Healthy Oceans

Clean air, water, and land are valuable commodities that need to be managed. Our estuaries and coastal waters are now subject to increased pollutants as a result of agricultural uses and the disposal of industrial and domestic waste. A major problem of the 21st century will be deciding what to do with the vast increases in waste of a growing population—forecast to double from six billion in the next century.

Healthy coastlines that support life and property, tourism and trade depend on the preservation of natural resources and the protection of clean air and water. The Florida Keys serve as an example of a valuable national asset that is under increasing pressure from both man-made and natural threats. Teasing out the natural versus human-caused disturbances so that coral reefs can be managed effectively is gaining momentum in Florida now.

Since the ocean comprises 98 percent of the free water on Earth—and healthy coastlines depend on it—determining the many components present in seawater is a key thrust of scientific research sponsored by NURP. The discovery that the deep sea may be as species-rich as a tropical rainforest comes at a time when pressure is mounting to use every available square foot of coastal land for development. As the number of land sites dwindles, the oceans are likely to become more prone to waste management in the future.

NURP researchers in this section discuss what they've learned about the effects of dumping on living resources and deep-sea biodiversity, as well as their concern about transmission of contaminants back to the human population. They will take you on a cruise to 20 coral reef sites from south of Miami to the Dry Tortugas to understand why the Florida reefs are doing so poorly in some places. They also discuss the effects of coastal development and natural processes, which circulate material from land into our rivers, bays, to the bottom of Lake Michigan and the continental shelf of the Atlantic Ocean. In deeper waters adjacent to Hawaii, using the opportunity presented last year when the submarine volcano Loihi off the big island of Hawaii erupted, they report effects on ocean chemistry.

In this chapter, NURP researchers focus on implementing more efficient ways to observe, monitor, and determine the ecological status of ocean resources.

Schoolmaster snapper.

Coral Reefs

Status of Reef Resources

On the surface, it might sound like a glamorous tourist package to dive the Florida Keys—a cruise to 20 coral reef sites from south of Miami to the Dry Tortugas. On closer examination, the cruise turns out to be a lot of hard work methodically counting plants and animals to assess changes in Florida coral reefs, and comparing reefs to see how they are faring relative to one another.

Most people don't know that Florida has the third longest coral reef system in the world, visited by more than a million divers each year—the centerpiece of a thriving \$1.2 billion annual tourist business. A major NURP-led research effort is underway by scientists and resource managers to understand why the reefs are doing so poorly in parts and to protect them from further harm.

Trying to determine what causes reefs to change is a difficult riddle to solve. Since a cold front swept down the Florida peninsula in 1975 and wiped out staghorn and elkhorn corals virtually overnight, Florida reefs appear to be on a decline that has not slowed in 20 years. Hurricanes, cold fronts, heat waves, marine disease epidemics, excess nutrients close to shore, fishing pressure, and ship groundings have all factored into the descent of corals. Congress established the Florida Keys National Marine Sanctuary in 1990 to understand those threats and to protect the coral reefs from over-exploitation. In July 1997, the National Marine Fisheries Service (NMFS) issued draft regulations to protect essential fish habitat—a move that sanctuary managers hope will lead to additional no-take fishing zones in the Keys where populations of important commercial and recreational fish are depleted.

What should a thriving, healthy reef look like? Warm emerald colored waters and tropical fish darting about rock formations are images we associate with coral reefs from travel brochures and television documentaries. Called the rainforests of the sea for their complexity and diversity of life, coral reefs are actually built by minute coral polyps that secrete calcium carbonate.

Most of the coral reef research to date has been done on shallow reefs in less than 20 m (66 ft) of water. In addition, no studies had looked at reefs throughout the Keys 360 km (220 mi) reef tract at the same time. In an effort to better evaluate the condition of deeper coral reefs and associated communities, a team of marine scientists embarked upon an ambitious Keys-wide expedition in 1995 with support from NURP, the Marine Sanctuaries Program, the National Park Service, the Munson and Macarthur Foundations, and Harbor Branch Oceanographic Institution. The research team was led by Steven Miller, associate director of NURP's Southeastern United States and Gulf of Mexico Center, and included Richard Aronson, a senior marine scientist at Dauphin Marine Science Lab, John Ogden, a marine ecologist with the Florida Institute of Oceanography, and Jim Bohnsack, an NMFS fisheries biologist.

What immediately impressed the researchers on the cruise as they began to compare coral reefs on a regional and local level were the "huge differences" in reefs, even if the reefs were fairly close to each other. "It wasn't always obvious why that should be," Aronson said. At sites throughout the Keys, researchers considered factors such as how many different


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Schoolmaster snapper.

kinds of coral, fish, and shellfish were present and how abundant they were, and whether or not there were signs of disease. The researchers on the Keys-wide cruise observed coral diseases, coral bleaching, excessive algae cover, and fewer fish at several of the reefs. The Dry Tortugas, west of the Florida Keys, appeared to be the exception. “The obvious hypothesis for why reefs are doing better in the Dry Tortugas,” Aronson said, “is that they’re untouched by man.” The most remote reefs are removed from poor water quality associated with coastal development, Miller added.

In the Dry Tortugas, scientists found more star coral (*Montastraea* and *Siderasterea*), and less disease (though it has since been found in high abundance at a few sites). In the Middle Keys, there appeared to be a relationship between how close or exposed reefs are to Florida Bay waters and how well they are faring. Reefs opposite bay channels are more exposed to colder, less salty, nutrient-rich waters, and appeared to be doing worse, Aronson said.

Since the coral reefs examined were at deeper depths and less exposed to fishing pressure (especially spear fishing), NMFS scientists on the Keys-wide cruise expected to find more economically valuable fish, but this didn’t prove to be the case. “Most of us were surprised by how few economically important species we saw at those depths,” Bohnsack said. “There were fewer grouper, snapper and grunt—the three big targeted fishing groups.” Yellowtail was the most abundant snapper with the highest density in the Middle Keys and the lowest density in the Upper Keys. Few grouper were observed, although the highest densities were observed in marine protected areas with either no spear fishing or no commercial fishing, Bohnsack said. Compared to shallower reefs, algae and coral-eating fish like parrotfish and surgeon fish dominated the deeper reefs.

Why are there more predatory fish in shallower coral reef environments where there is more fishing pressure? Why are there fewer predatory fish and more herbivorous fish and macroinvertebrates on deeper reefs? There are hypotheses that need to be tested in the future. “It could be overfishing,” said Ogden. “There are very few large predators on the reefs, and when little fish are released from predation their populations grow. These fish take over areas of coral and kill it by nibbling away at it, and on dead coral, algae grows.”

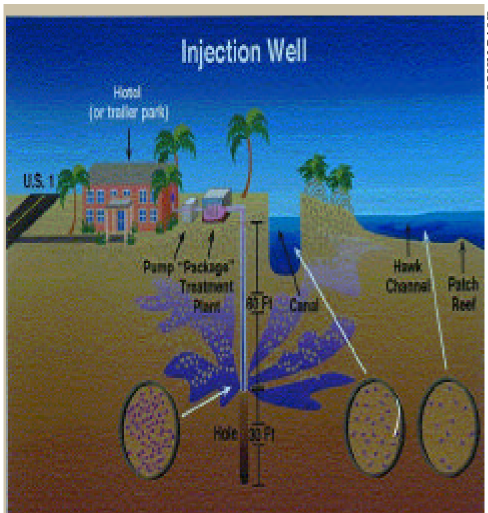
Water Quality

Another mystery that NURP-funded researchers have set out to solve is whether or not nutrients like nitrogen and phosphorus from sewage effluent, agriculture and urban runoff that appear to have harmed nearshore reefs are making their way out to offshore coral reefs. Excess nutrients act like fertilizers and promote growth of algae that may smother some coral reefs. Wastewater from injection wells and septic tanks in the Florida Keys are found in surface marine waters and could be part of the problem. With no centralized wastewater disposal system in the Florida Keys, except for Key West, residents depend on more than 30,000 injection wells, septic tanks, and cess pits. Since 1993, John Paul and Joan Rose, marine microbiologists at the University of South Florida, have studied the impact of these waste disposal systems on Key Largo. Similar studies are also being conducted by Eugene Shinn, project chief of the U.S. Geological Survey, who installed monitoring wells in the Keys, including at NURP’s *Aquarius* habitat at Conch Reef, to test for contaminated groundwater in the marine environment.

Typically, bacteria migrates only a short distance from a septic tank’s drain field, but this doesn’t always happen in the Florida Keys where groundwater permeates through the cracks and fissures in the porous limestone bedrock. Measurements of the rate of bacterial migration from its original source to offshore reefs were as fast as 20 m (64 ft) per hour in some of Paul’s experiments.

Paul and Rose used a harmless viral tracer to test whether fecal bacteria from injection wells were moving through groundwater into the marine environment. Bacteria flushed down toilets in domestic residences showed up within eight hours in groundwater, and within 36 hours it was detected in Florida Bay. By 53 hours, the tracer appeared in a canal on the other side of the highway, on its way to Hawk Channel and the Atlantic Ocean. A second experiment indicated that the tracer could move from the waste disposal well to the canal in less than eight hours if strong north winds occurred at the same time.

“We conclusively showed the connection between wastewater disposal practices and the marine environment,” Paul said.



JOHN PAUL

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Natural Variability

Clouding the issue of reef protection are natural factors that affect reefs, for example, variations in climate and water temperature. Conch Reef, eight miles southeast of Key Largo, is removed from the pollutants that Paul detected closer to shore. Bathed in the clear, clean waters from the Gulf Stream, Conch Reef provided marine ecologists Jim Leichter and Mark Denny of Stanford University with an ideal test site for studying natural factors that influence the growth and survival of corals.

The researchers discovered that internal waves push cool water up onto the reef tract from a seaward direction, bringing with it a high concentration of dissolved nitrogen and phosphorus. These nutrients can influence the growth of benthic algae harmful to reefs quite apart from sewage-derived nutrients introduced from shore. Rapid temperature fluctuations—on the order of more than five degrees within a few minutes—are also problematic for corals.

Just as fewer predatory fish were found at deeper reefs where researchers assumed there would be more fish, a surprising result of this research was that temperature and nutrient variation increases with depth. Previously researchers thought deeper reefs were exposed to relatively constant conditions compared to shallow reefs, which are exposed to variable sunlight, temperature, and breaking waves. These findings show that some of the most common assumptions can be wrong. "Our work reveals aspects of the environment that you could never observe from the surface," said Leichter.

To understand how humans affect coral reefs, it's critical to understand what naturally influences their survival. Separating the difference between natural variations and human-induced influences is extremely important, especially in regions like Florida where the coral reefs are located toward the northern limit of where it's possible for them to grow and where natural baseline variation may be very high. Since Florida's reefs are already a marginal habitat, reefs have developed adaptations to the physical environment–survival mechanisms that scientists are just beginning to understand. At some point, the combination of both natural and man-made influences can tip the balance against the well-being of corals.

The effective management of reefs will depend on this understanding of how natural and human influences impact reefs.

Cycling of Materials

Contaminants

The unique chemical properties of water make life possible on Earth. Understanding the chemical constituents of seawater and their distribution is important in order to determine such things as the fate of contaminants in the environment, the critical role that chemical constituents play in the production of organic matter, and their impact on marine life. To get a better picture of how ocean chemistry operates, scientists supported by NURP are studying the effects of coastal development and the natural processes that circulate material from the land into our rivers, bays, to the bottom of Lake Michigan, and the Atlantic and Pacific Oceans.

Undersea technology helped scientists advance analytical chemical techniques and sampling methods to learn more about the correlation between coastal and biological processes and chemical constituents in the ocean. Lake Michigan serves as an ideal laboratory for studying chemical processes because the flushing time for sediments in the Great Lakes averages about 100 years, compared to the mixing time of the ocean that occurs on a scale of up to 1,000 years. J. Val Klump, a biogeochemist with the Center for Great Lakes Studies, received NURP support to study what happens to chemical constituents once they settle out and enter the bottom sediments. Lake Michigan is subjected to the pressures of an industrial and agricultural coastline. With its paper mills and dairy farms, the lake is the ultimate recipient of anthropogenic nutrients that fuel anoxic conditions in nearby Green Bay.

A remotely operated vehicle (ROV) used benthic chambers for collecting bottom sediments. "Without this information, it would be impossible to understand the system," said Klump, who designed the sampling system. Cesium 137, a radionuclide used in chemical weapons testing in the 1970s, serves as one excellent tracer for looking at how sediments get mixed by worms, amphipods, fish, and storm events. These physical processes appear to play an important role in the resuspension of chemicals like ammonia, organic nitrogen, and carbon dioxide.

His research findings also have implications for how pollutants cycle through the Great Lakes and marine environments. "The good news is that contaminants are rapidly transported to the sediments where their concentrations are reduced," Klump said. "The bad news is they're entering into a long-term box, which continually exposes the overlying water to the contaminant."

Carbon Cycling

Scientists around the world are trying to understand the role that the ocean plays in regulating the amount of carbon dioxide in the atmosphere, and the manner in which the ocean responds to increases in atmospheric carbon dioxide as a result of the burning of fossil fuels, deforestation, and other anthropogenic sources. Unlike the open ocean, the cycling of carbon in the coastal ocean is difficult to understand because it varies with large seasonal shifts in the productivity of marine life, as well as the immediate exchange of materials between the seafloor and the surface.

To understand how carbon cycles through the ocean, scientists must first know how all the elements that impact carbon distribution and forms interact, said George Luther, a chemical oceanographer at the University of Delaware. Toward achieving this goal, chemical oceanographer Clare Reimers of Rutgers University and Luther pooled their array of technical electrode designs to take *in situ* measurements of pH, dissolved oxygen, manganese, iron and sulfide in coastal sediments of the New York Bight in 1997 with NURP funding.


J. VAL KLUMP

Green Bay, Lake Michigan.

"When you see black on a banana, that's decomposition," Luther said, "but we can't see that going on at the bottom of the ocean." Using an ROV with *in situ* probes (gold wire electrodes with a thin coat of mercury), the researchers are able to measure the concentrations of dissolved oxygen, iron, manganese and sulfide in coastal sediments. As phytoplankton in surface waters die, they rain down to the sediments at the bottom where they are decomposed by bacteria. The researchers observed that bacteria consumed all the oxygen within the top 0.8 in (2 mm) of the sediments. In order to decompose organic matter residing deeper in the sediments, the bacteria use manganese oxides and nitrate to about 1.2 in (30 mm). Iron oxides are used deeper down, and then sulfate. "This is important in the cycling of carbon in the ocean," Luther said. "There's so much organic matter being produced and cycled in the coast, that the predominant oxidant may not be oxygen anymore—it may be manganese or iron oxide or sulfate. We still don't know all the intricacies of these interactions, and how they effect the global carbon budget."

The researchers have most of the tools for measuring organic matter decomposition in coastal sediments. Luther hopes that an autonomous underwater vehicle (AUV) with electrode sensors will be used in the future to measure chemical processes in deep ocean sediments where the concentrations in chemicals are less than the coastal ocean. Since the continental slopes and deeper waters constitute 93 percent of the sea, estimating the fate of materials and how long they take to move around the deep ocean, and their effect on the environment is an important area of ocean research.

Hydrothermal Vent Fluids

An ideal opportunity to use the deep ocean as a laboratory for understanding ocean chemistry arose recently when the submarine volcano Loihi off the big island of Hawaii erupted. A pervasive flow of minerals, including copper, iron, manganese, zinc, potassium, and calcium, streamed out of the mounds and hydrothermal chimneys of Loihi. NURP scientists were able to visit the site within days to begin investigating the nature of fresh vent fluids. Loihi along with other ridge and vent fields, provide most of the mineral resources on Earth. The timely Loihi eruption gave NURP researchers a “geochemical telescope” into the Earth’s mantle to sample how minerals are formed, said Alexander Malahoff, director of NURP’s Hawaii and Western Pacific Undersea Research Laboratory, who led a series of dives to Loihi.

Chemicals in the vent fluid also support huge swarms of microorganisms that festoon themselves on rocks like white teeshirts flapping in the water. During several dives to Loihi two years ago researchers would observe huge bacterial mats that would disappear from one day to the next when rubble would prevent magma from interacting with seawater. “It was kind of scary,” said microbiologist James Cowen of the University of Hawaii. “You’d go back the next day and the bacteria were gone from one site, but found further away.”

Vents provide a continuous supply of minerals and gases such as carbon dioxide and hydrogen sulfide that have played a major role in the evolution of the oceans and atmosphere, and conditions favorable for life. These are topics of other NURP projects.

The tools NURP scientists are developing to take more systematic measurements of the distribution of chemical constituents in the ocean and in sediments are also useful in other coastal ecosystems. By continuously monitoring the ocean over large spatial scales, as researchers are doing at LEO-15 (and plan to do this year at Loihi at a Hawaii Undersea Geo-Observatory), researchers may eventually be able to forecast hypoxic or volcanic events. Developments in ocean chemistry are enhanced by rapid advancements in technology. This underscores the importance of technology in the context of the global environment.

Deep-Sea Dumping

The discovery that the deep sea may rival tropical rainforests in the diversity of life comes at a time when pressure is mounting to use every available square foot of coastal land for development. A major problem of the 21st century will be deciding what to do with the vast increases in waste produced by a growing world population—forecast to double to 12 billion in the next century. The effect on the oceans must be understood for the good of the public, and national and international decision and policy makers. As the number of


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Schematic of *Pisces V* moving along the north wall of Pele’s Pit at the undersea volcano, Loihi.

landfill sites dwindle, the oceans must be evaluated as a possible option for disposal of a larger fraction of human wastes. At present, most waste disposal in the ocean is banned by national policy and international law as a result of the environmental abuses since the industrial revolution.

With more than 80 percent of the ocean at depths of more than 3,000 m (9,840 ft), the deep-sea floor seems safe from the man-made disturbances that threaten terrestrial and coastal environments. But is it? NURP recently supported numerous projects in the oceans and Great Lakes to determine the impact of waste disposal on bottom-living animals. Of particular concern to researchers are the effects of dumping on living resources and deep-sea biodiversity, and the possible transmission of contaminants back to the human population.

In the most detailed study ever done related to the impacts of ocean dumping, NURP-funded scientists led by benthic ecologist Fred Grassle of Rutgers University and geochemist Michael Bothner of the Woods Hole U.S. Geological Survey documented the impact of 42 million tons of wet sewage sludge dumped at the 106-Mile Dumpsite, 106 nautical miles southeast of New York Harbor. This dumping in water depths of 2,500 m (8,000 ft) caused local increases in pollution and restructured the deep-sea community of organisms. During the course of six years, studies showed that a significant fraction of the sludge material dumped by barges reached the ocean bottom slightly west of the area where it was discharged, and that it had measurable effects on the metabolism, diet, and composition of organisms that lived there. This was contrary to expectations that the sludge might not reach the bottom, but would instead be diluted and swept away.


NURP/MAB

A trawl sample at the 106-mile dumpsite shows the diversity of life at 2,500 m.

Sludge disposal at the 106-Mile Dumpsite was curtailed in July 1992. “This provided additional opportunities to examine the long-term dispersal and effects of waste material in the deep-sea environment,” Bothner said. While the effects of sludge dumping appeared to be abating in the vicinity of the dumpsite, an additional chapter to the story of the 106-Mile Site still remains to be written. Levels of silver appeared to be on the increase 50 nautical miles south of the dumpsite, as did the densities of sediment-dwelling organisms. The recovery at the dumpsite coincided with changes in habitats further downstream as resuspended materials were transported to the south of the dumpsite.